Wiring Nanodevices: Start with Happy Atoms

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Nanotechnology may hold the promise of ever-shrinking devices, but if those gadgets can't be wired, they're just big ideas with unrealized potential. Fortunately, scientists like Physics Professor Hanno Weitering and his colleagues from Oak Ridge National Laboratory are addressing this challenge. Results from their recent experiments with metallic nanowires are published in "Charge-order fluctuations in one-dimensional silicides," which appears in the July issue of *Nature Materials*.

What the Weitering collaboration found is that compounds made from yttrium and silicon will assemble themselves into nice, uniform nanowires when they're laid down on a base layer (called a substrate) of silicon.

"The atoms are happy in that configuration," said Weitering, who holds a joint faculty appointment with ORNL. "Why the atoms are happy in that configuration; that's a big question.

"What we explained in the paper was why the wires tend to grow in one direction," he continued. "We combined yttrium and silicon, and that forms a silicide—a compound. The compound's crystal structure is such that it matches very nicely with the silicon crystal structure of the substrate, but only along one direction. What surprised us is that (the wires) are so nice and long and uniform. You don't see that very often."

Typically when scientists grow materials they might get short segments, or wires of different height or width. With the yttrium-silicon compounds, the research team fabricated uniform wires in one dimension, meaning the system is confined as if along a straight line, or a railroad track, so the electrons have no way to avoid one another.

Also among the group's findings was the capture of a Peierls instability, a phenomenon identified by physicist Sir Rudolph Peierls in 1955. Weitering describes it as a generic name for electronic instabilities; hiccups in the distances between atoms arranged in a chain. While he and fellow physicists like Distinguished Professor Ward Plummer have seen these distortions in two-dimensional materials using a scanning tunneling microscope (STM), it's difficult to pin them down in one dimension.

"What we now show with this paper is that we have a chain that is truly isolated and we actually have seen this kind of instability in the chain," Weitering said. "We are back at one dimension, and we captured the instability with the STM."

Getting a clearer picture of nanowire structure could translate into taking tiny devices from concept to reality.

"You can think of making all sorts of nanodevices, but eventually you have to wire them up," Weitering said. "When the devices become small, the wires have to become small. One of the issues with very small wires is this Peierls instability, because people will tell you that you cannot make an atom wire; (or that) you can make it but it will not conduct. For that reason there is always a lot of interest in the conductivity of one-dimensional materials."

Another interesting feature of the yttrium-silicon wires is that they exhibited built-in junctions. Weitering explained that when the wires grow slightly irregularly—wider on one side than the other—the whole wire will be "happily metallic" at room temperature, but at low temperatures the thin side will become an insulator and the thicker side will stay a metal.

"So what you create is actually a metal-semiconductor junction," he said.

And why do such junctions matter? Because they can be used as rectifiers in electronics, converting alternating current to direct current.

The research is sponsored by the National Science Foundation and the Department of Energy, but also, interestingly enough, by the National Institutes of Health. The latter may seem an odd fit for condensed matter physics research, but it turns out that tiny wires might find an application in the field of genetics.

Weitering explained that there have long been proposals to electrically sequence DNA. One idea is to force DNA molecules through a pore in a membrane, connecting metallic electrodes on either side to constantly measure current voltage as the DNA moves through. Every nucleotide base pair is predicted to have its own electrical characteristic, and a constant reading of electrical properties could be one means to sequence DNA.

“But in order to distinguish neighboring base pairs, you need to have electrodes that are very tiny,” Weitering said, emphasizing that at present this approach is an idea that hasn’t been proven. “There is a lot of effort in trying to do DNA sequencing these days,” he said. “This is just one possibility based on nanotechnology.”

The *Nature Materials* paper is available online. Co-authors are Changgan Zeng (UT Physics Department and the University of Science and Technology of China Hefei); and P.R.C. Kent, Tae-Hwan Kim, and An-Ping Li (all of the ORNL Center for Nanophase Materials Sciences). The experimental work was done mostly at UT by Zeng, a former postdoc in the Weitering group who is now a professor at the University of Science and Technology of China in Hefei. The very extensive theoretical work was done by Kent, a staff member at the CNMS.